Recent Upgrades of the Optical Synchronization System at FLASH

FEL Seminar

Jost Müller on behalf of the LbSync team
Hamburg, 5. February 2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Outline

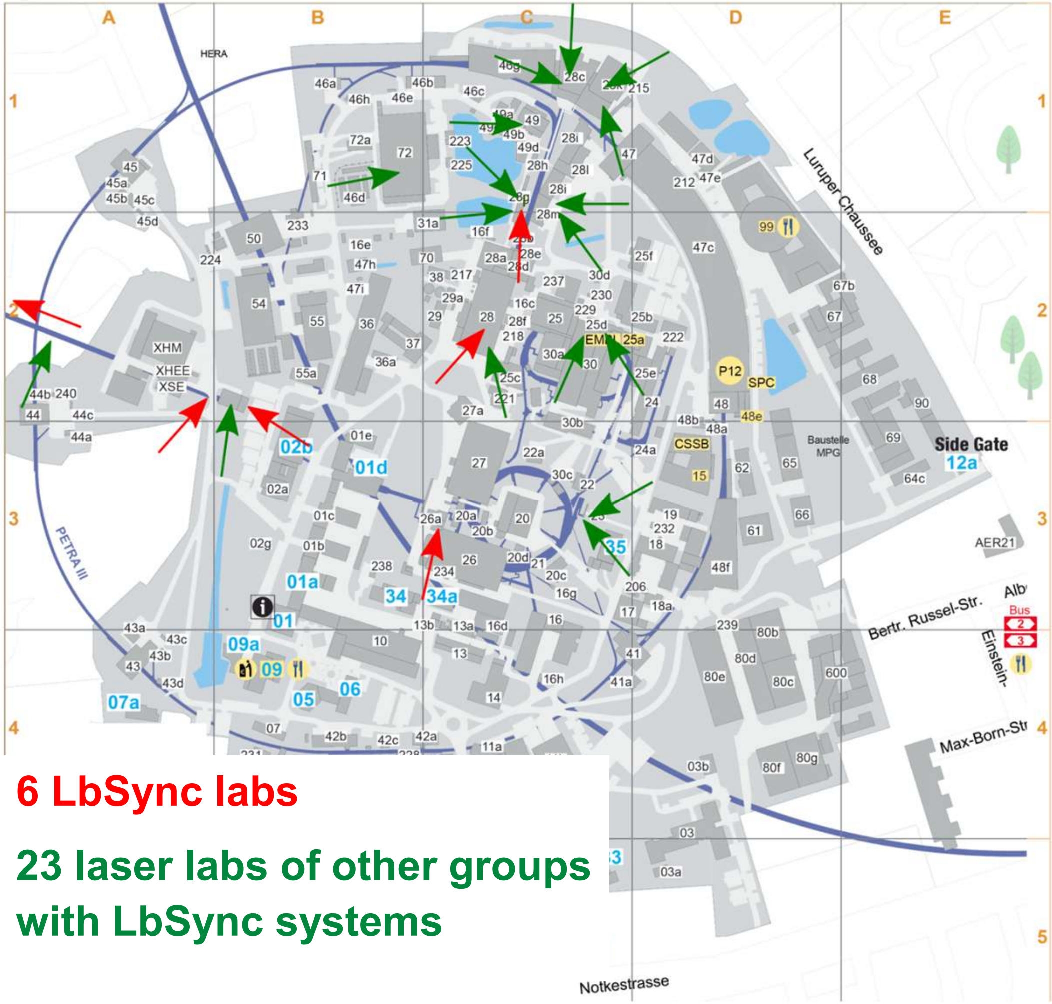
Introduction

LbSync Activities at DESY

Group Structure and Historical Overview

LbSync team: currently 7 members

- 2004: first developments started in collaboration with MIT, hosted in FLA group,
- **2008: LbSync operation at FLASH started**
- 2010: project moved to MSK
- 2017: first experiments at XFEL using optical synchronization
- **2018: renewal of FLASH LbSync system**
- 2018: SINBAD injector laser synchronization
- 2019: finish installation of XFEL LbSync system
- **2020: finish renewal of FLASH LbSync system**
- 2020+: installation LbSync at SINBAD



6 LbSync labs

23 laser labs of other groups with LbSync systems

FLASH Optical Synchronization Upgrades 2018+

Why Upgrading?

Performance

- MZI-based MLO synchronization: **jitter 30 fs → 3 fs, drift stability**
- single-mode fiber (SMF) replaced by polarization-maintaining (PMF)
  - **jitter 3 fs → 0.5 fs**
  - enhanced drift stability
- MicroTCA.4-based system
- laser synchronization: **jitter 15 fs → 5 fs**

Space

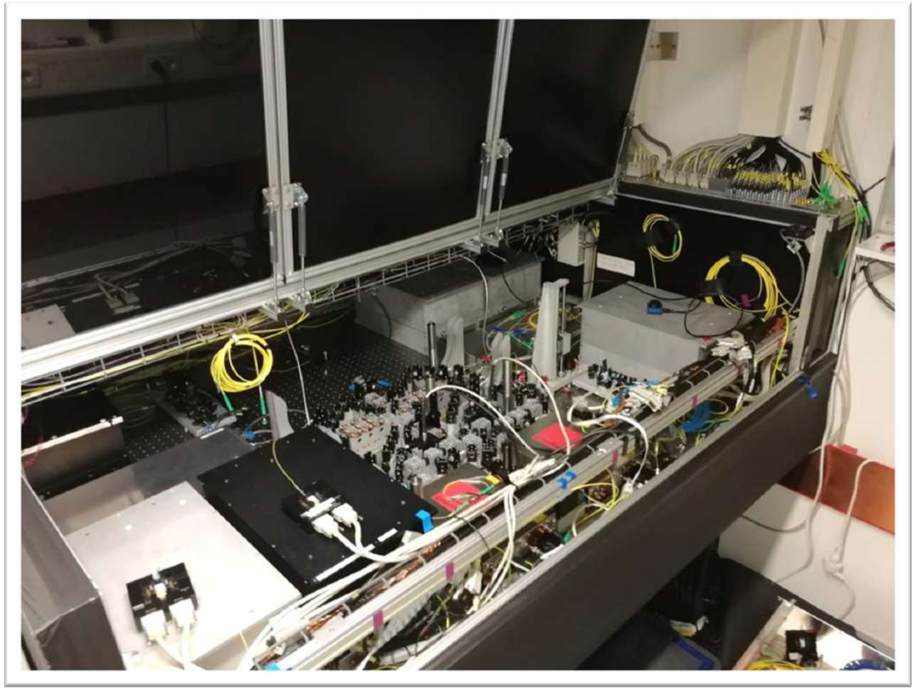
- old structure (optical table, infrastructure, etc) allowed **only 8 links**
- **24 optical links required** including potential future upgrades

Discontinued Components

- VME system
- migration of all control electronics to MicroTCA.4

Reliability & Maintainability

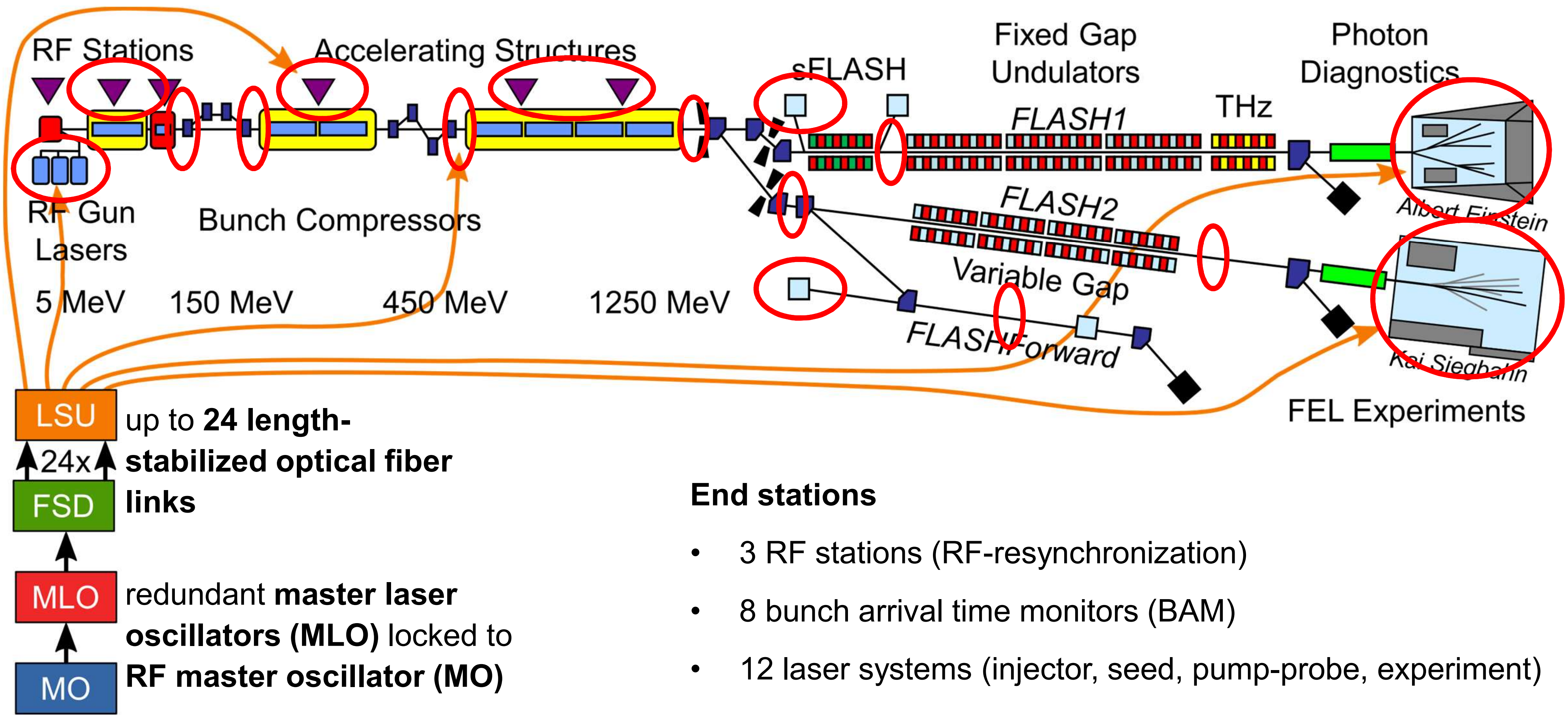
- same setup like at the XFEL
- software / firmware



Optical Reference & Distribution

FLASH Optical Synchronization System

System Overview



up to **24 length-stabilized optical fiber links**

redundant **master laser oscillators (MLO)** locked to **RF master oscillator (MO)**

End stations

- 3 RF stations (RF-resynchronization)
- 8 bunch arrival time monitors (BAM)
- 12 laser systems (injector, seed, pump-probe, experiment)

Main Synchronization Laboratory XFEL

Infrastructure

- strict separation of optics, electronics, general working space
- **no electronics in optics part** → no heat sources, EMI, vibration
- environmental stability → dT < 0.1K / dRH < 5%
- EMI → **proper grounding** (single grounding point), optical cables used if possible, separate potential EMI sources from critical systems
- acoustics & vibrations → **optics part acoustically isolated**
- UPS for operation-critical systems

main optical table at XFEL, UG5

Master Laser Oscillator (MLO)

The Main Optical Reference

Oscillator

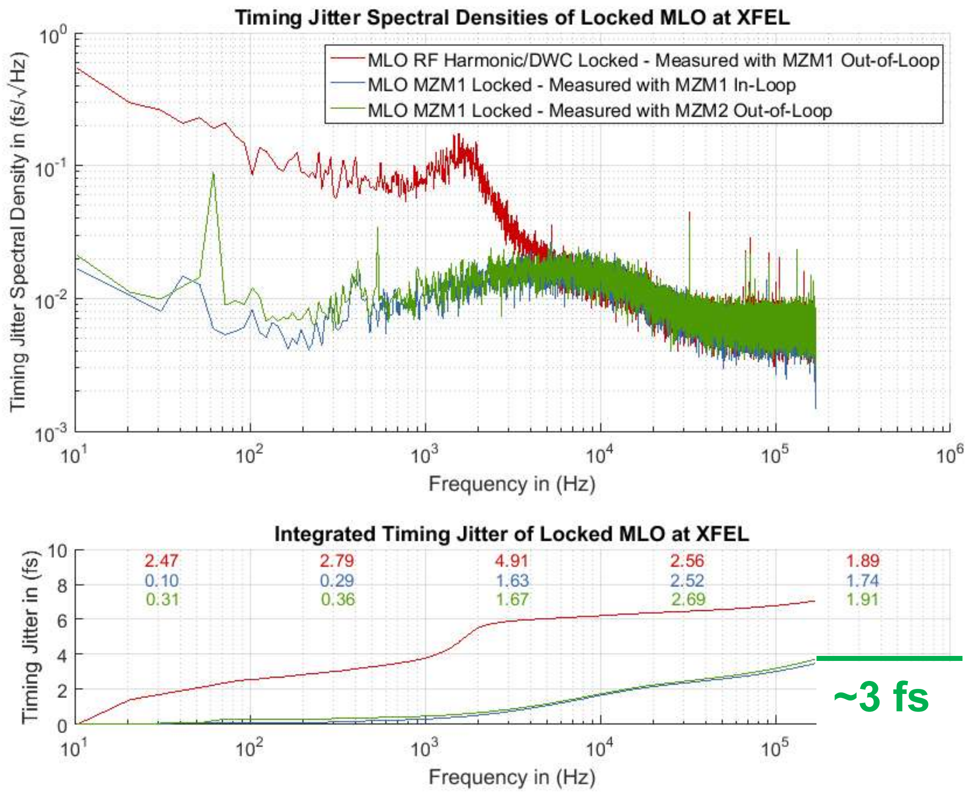
- commercial (NKT, former Onefive)
- SESAM-based, passively mode-locked
- ultra-low phase noise, Erbium, 1550 nm
- 24/7 operation

Synchronization

- laser-to-RF based, **low-noise (~3 fs)**, low-drift, amplitude insensitive locking scheme

Redundancy

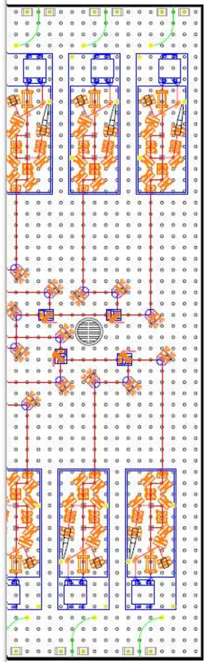
- two similar laser oscillators
- both synchronized all the time, individual setups, identical timing
- fast switching of active source: no link lock lost, timing preserved



Free-Space Distribution

Laser Bea

- **Superl**
  - therm
  - no bi
- second
- space f
  - ident
- 8 link s
  - arbitr
- table c
  stable
  - ≪ 0.
- **online**
  (air, tab



CAD drawing courtesy of C. Sydlo

LSU: Principle of Operation

Measurem

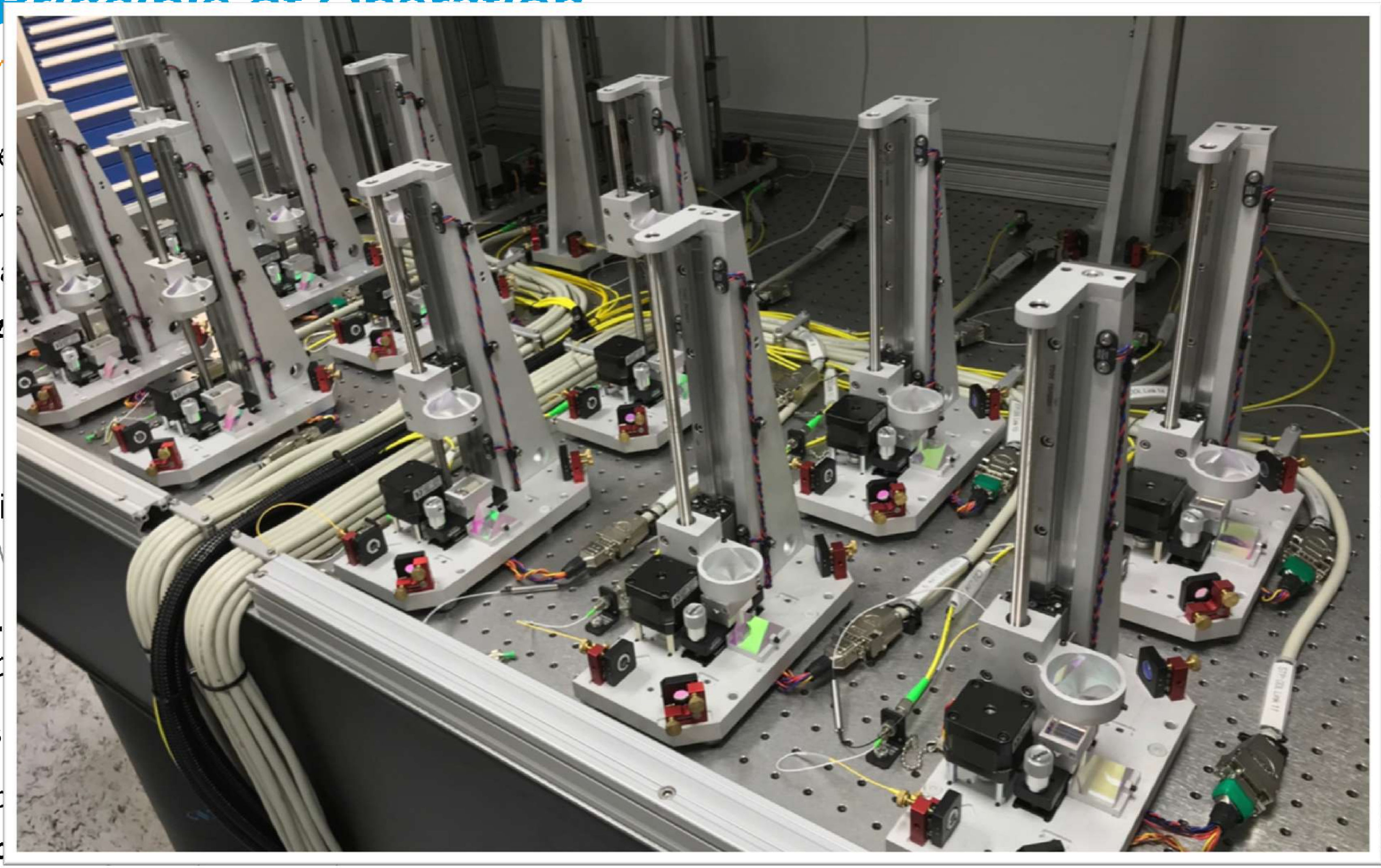
- balanc
  - inser
  - typic
- **polariz** related

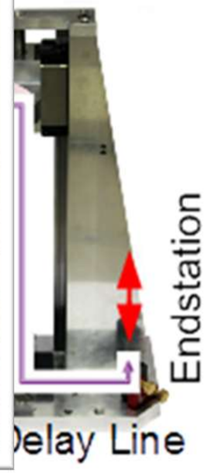
Detection

- self-bui (0.1 m
- **MTCA.** and mo

Actuators

- piezo
- **optic**

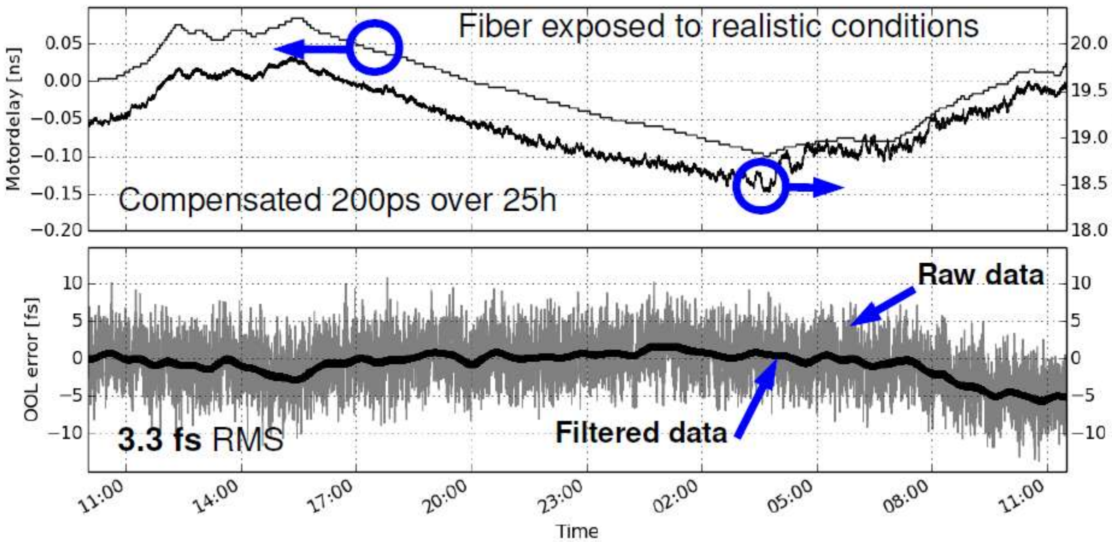


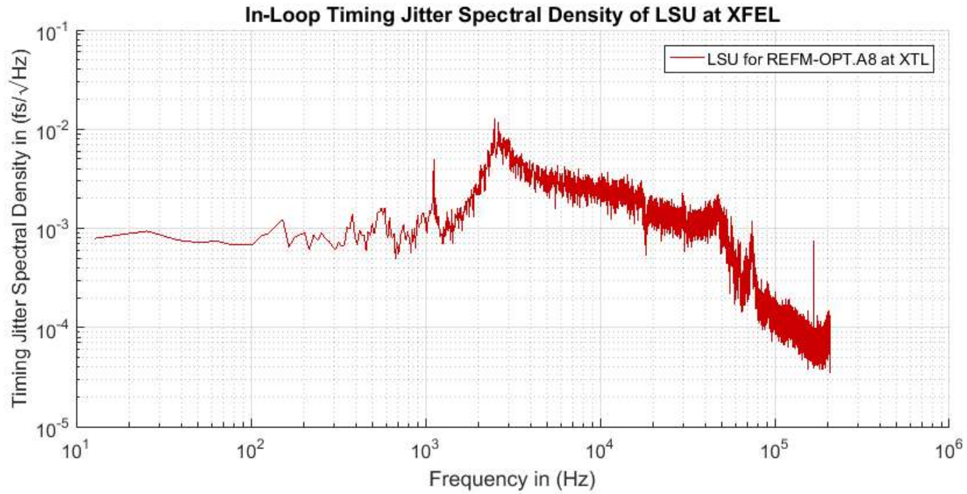


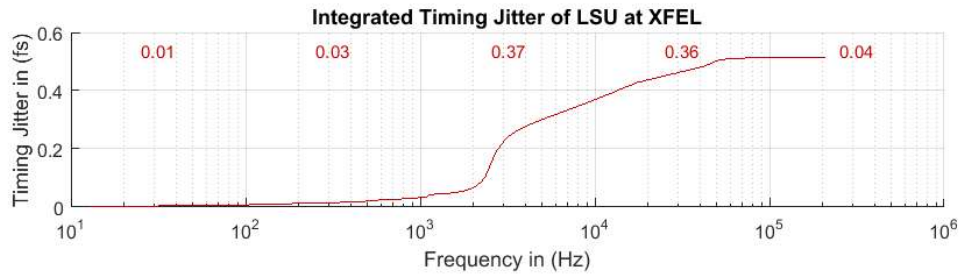
Link Stabilization Units (LSU)

Measurement Results

Link-Stabilization-Units: Out-of-loop measurement







Performance

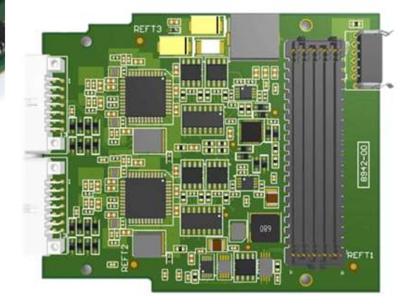
- jitter (rms) < 500 as
- drift: 3.3 fs / 24 h
- observed drift compensation at XFEL: **up to 200 ps/km!**

MicroTCA.4

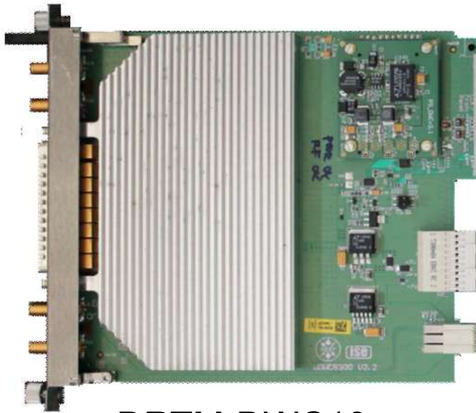
MicroTCA.4 for LbSync

- **DRTM-DWC10**: 10 channel RF down-converter for laser synchronization
- **DRTM-LASY**: dedicated laser synchronization board
- **DRTM-AD84**: ADC board for link signal detection
- **DRTM-PZT4**: 4-Ch, ±100V piezo driver for link & laser synchronization
- **DAMC-FMC20**: FMC carrier board laser synchronization
- **DAMC-FMC25**: FMC carrier / FPGA link synchronization
- **SIS8300L2**: 10-Ch 125 MS/s 16-bit ADC, 2x 16-bit DACs, Virtex FPGA
- **DFMC-MD22**: 2-Ch, encoder
- **DFMC-UNIIO**: universal I/O, MLO/shutter control
- **DFMC-AD16**
- **X2TIMER**

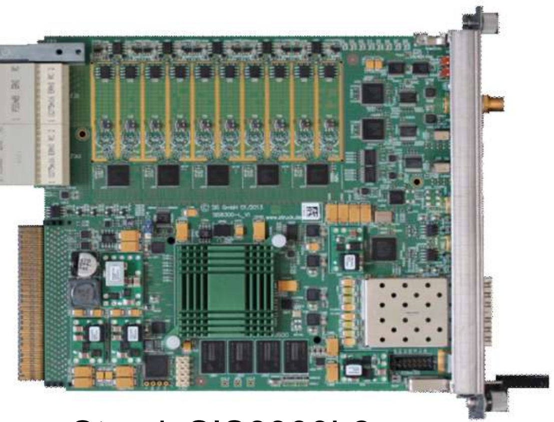
DAMC-FMC20



DFMC-MD22



DRTM-DWC10



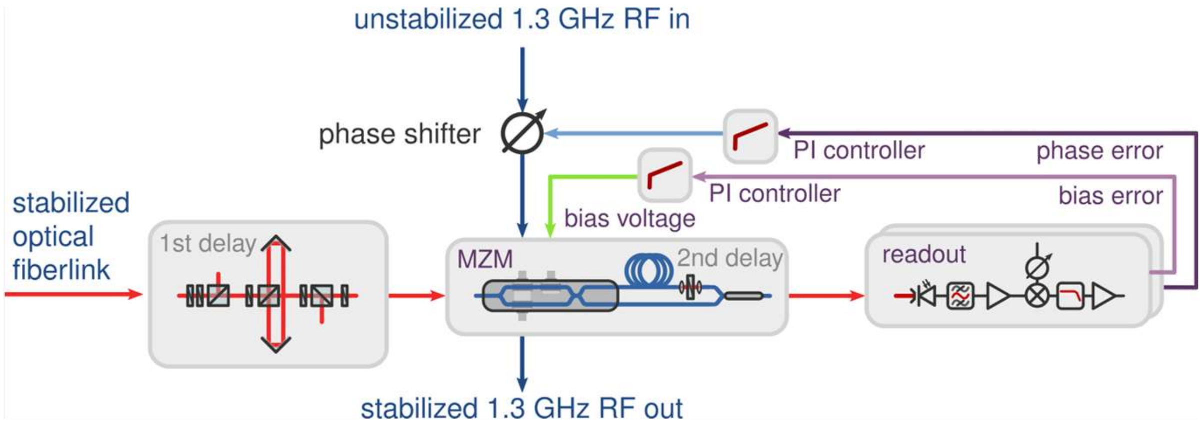
Struck SIS8300L2

End Stations

The Optical Reference Module (Refm-Opt)

Femtosecond RF Reference Phase Stabilization

- uses a stabilized fiberlink from the pulsed optical synchronization system as reference
- employs a **drift-free L2RF phase detector**
- locally **re-synchronizes the 1.3 GHz** RF reference with femtosecond precision in a PLL
- phase-stabilized Wilkinson splitter to provide multiple outputs



Engineering

- fully integrated stand-alone 19“ module
- temperature and humidity stabilized optical compartment

Laser Synchronization

Laser Synchronization Schemes – Comparison

RF

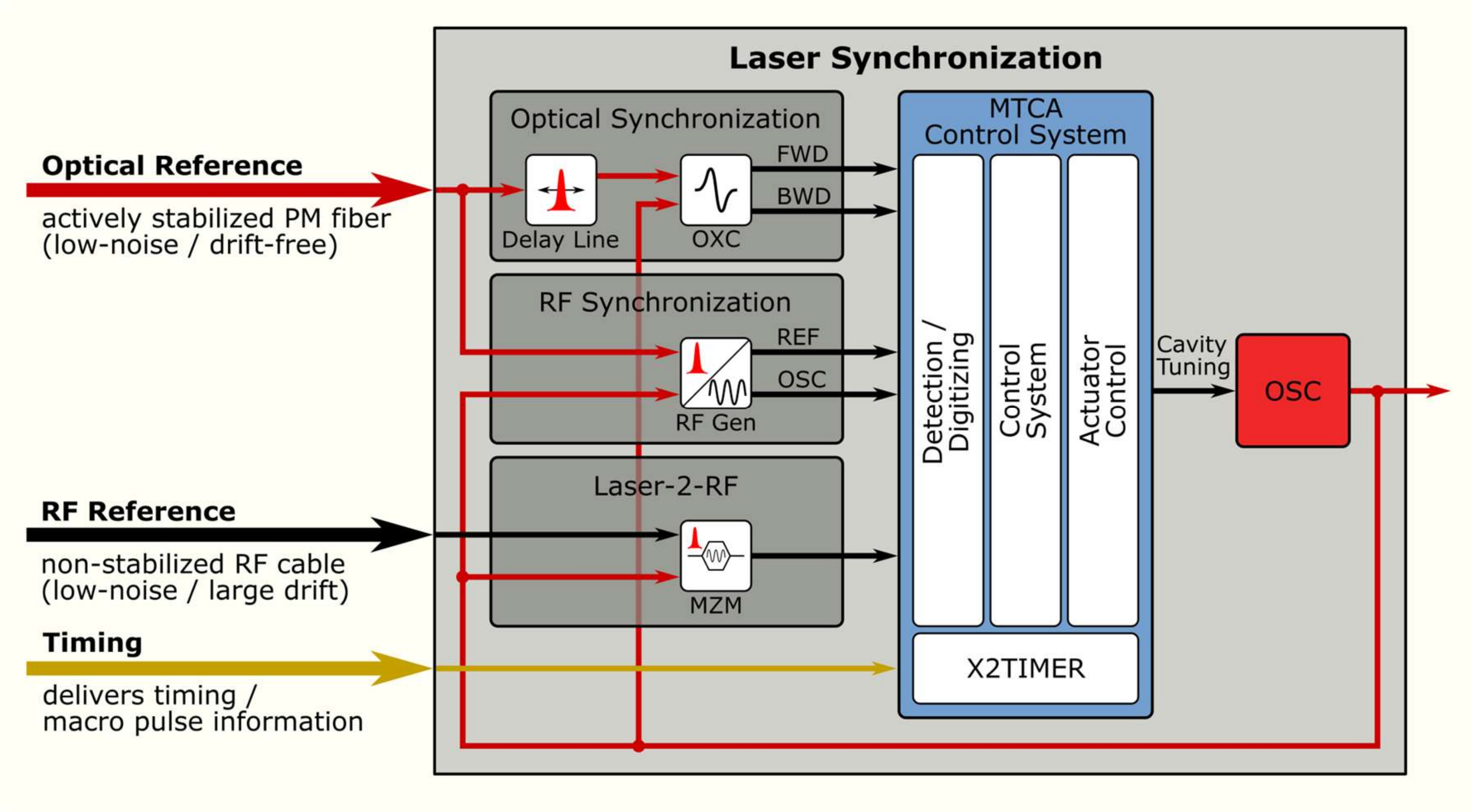
- easy to implement
- low-jitter (<20 fs)
- large drift (hundreds of fs), AM-to-PM

Laser-to-RF

- low-jitter (~3 fs)
- low-drift (<10 fs)
- requires high-power budget
- implementation challenging

Laser-to-Laser

- ultra low-jitter (<1 fs)
- low-drift (<10 fs)
- implementation challenging



Laser Synchronization – RF-based

Based on Conventional RF Synchronization Scheme

Concept

- RF mixing scheme: reference at 1.3 GHz mixed with 1.3 GHz + f_{rep}
- IF signal at f_{rep} is digitized by fast ADCs (clock derived from reference) and evaluated regarding magnitude/phase
- no DC error signal

  → locking to arbitrary phase set point possible

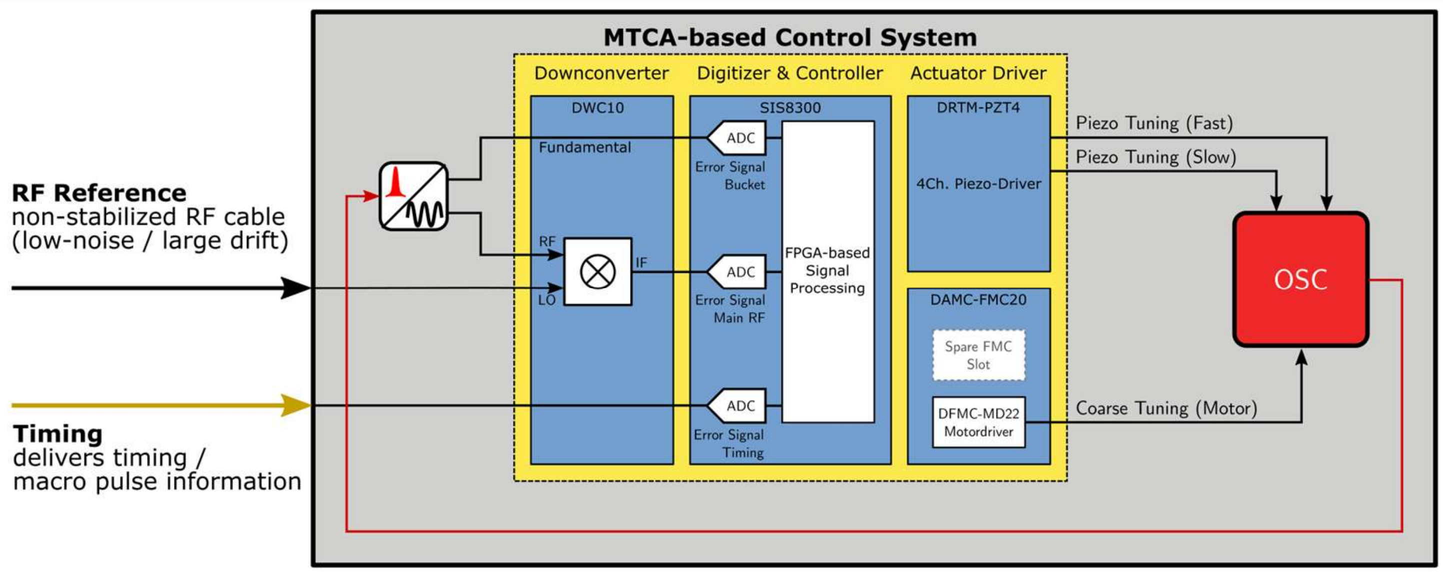
  → less EMI-related distortions

  → no DC-offset drifts

  → better 1/f noise performance

MicroTCA.4-based controls

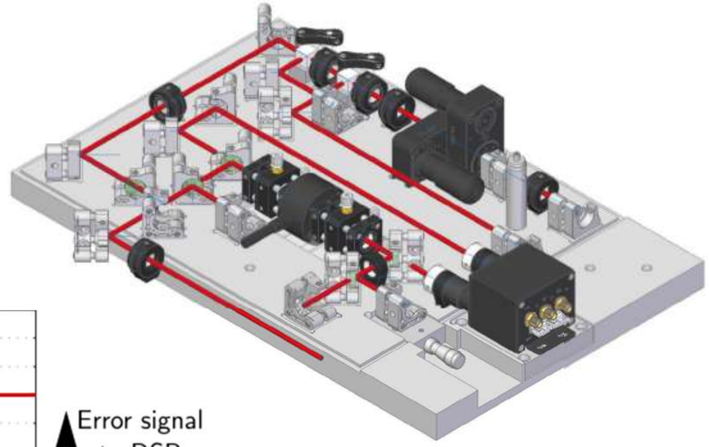
- variety of oscillator configurations supported (1 or 2 piezos, motor/piezo stage/temperature tuning, …)
- dedicated laser sync RTM under development

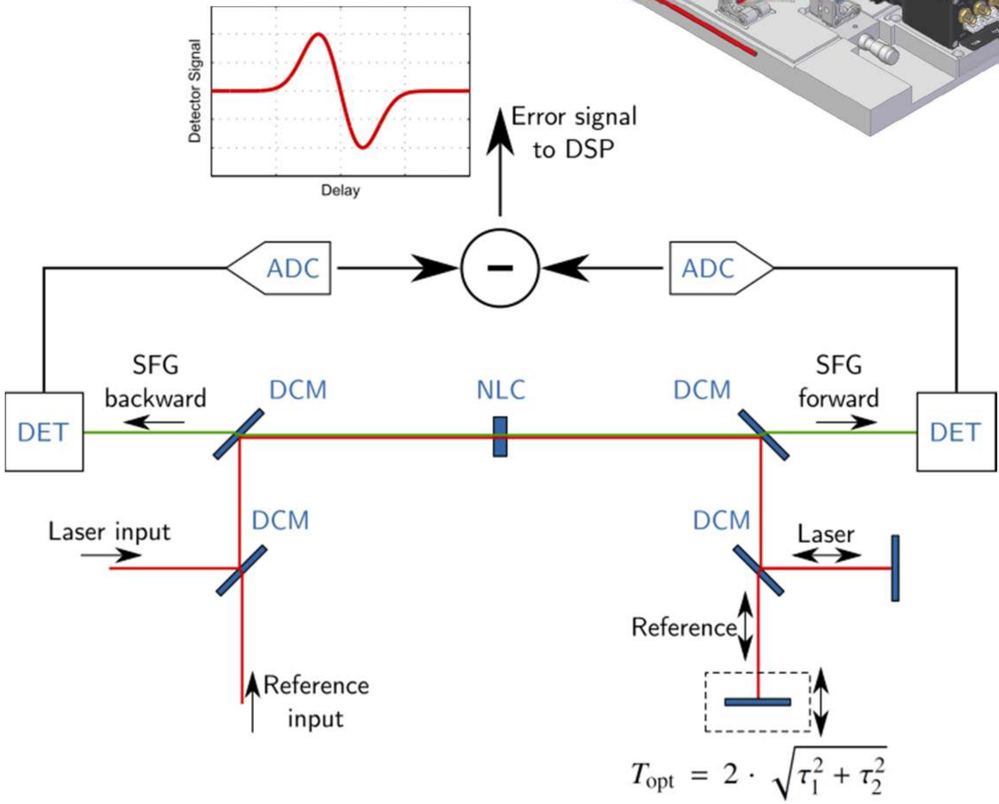


Laser-to-Laser Synchronization – Concept

Ultra-low Jitter, drift-free Laser-to-Laser Synchronization

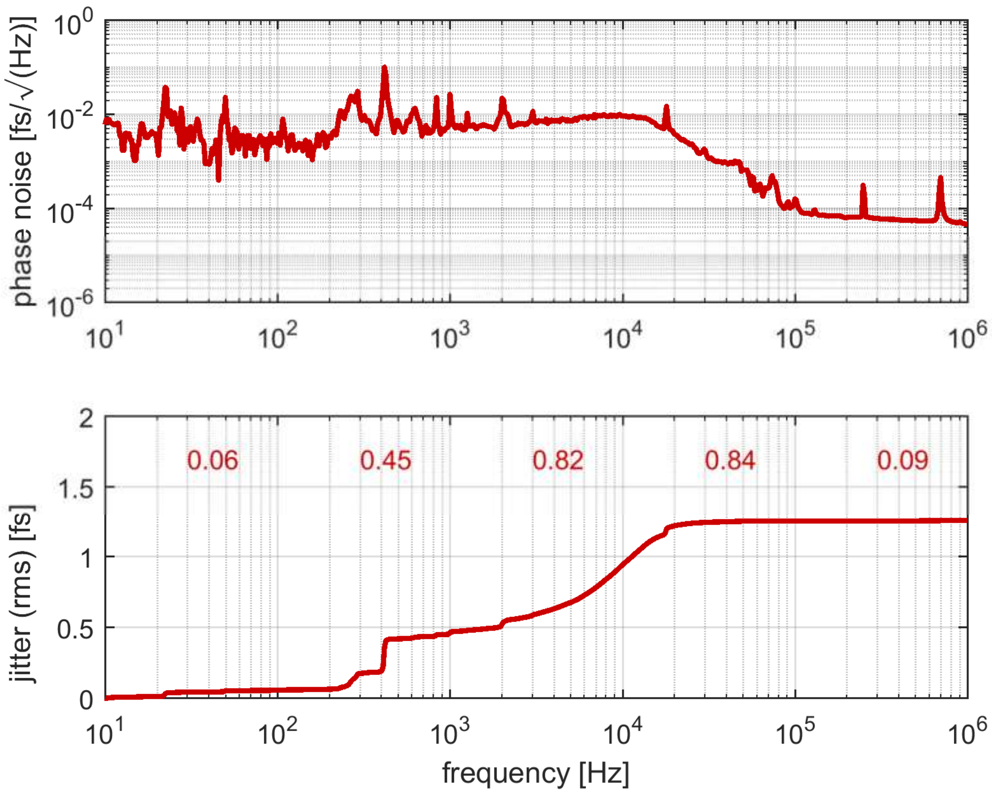
- **all-optical scheme** for timing error measurement
  - high accuracy: <100as/mV
  - pure phase-sensitive measurement
  - no drifts due to RF cables etc
- based on **two-color balanced optical cross-correlation**
  - aim: precisely measure the timing error between two pulsed laser sources
  - twofold sum-frequency generation in a non-linear crystal (BBO/PPKTP/PPLN)
  - differential scheme eliminates AM-related influence on the phase measurement
- one **common design** covering requirements of different laser systems

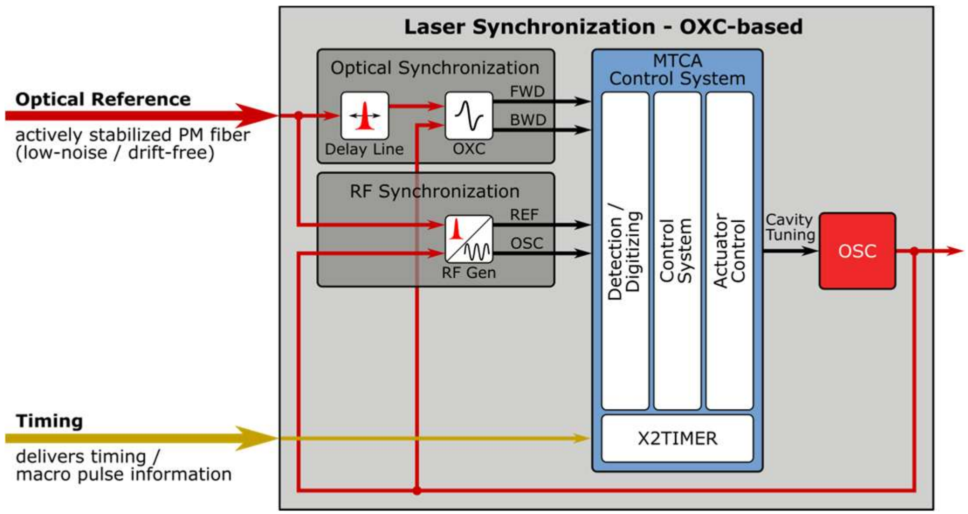




Laser-to-Laser Synchronization

Performance





- laser oscillator: Origami-15
- reference via 3.5 km stabilized fiber link
- PPKTP-based OXC
- **1.3 fs rms in-loop jitter** [10 Hz..10 MHz]

FLASH LbSync Upgrades 2018+

FLASH LbSync Upgrades 2018+

Timeline

Phase 1 (summer 2018)

- **complete removal** of old components (optical table, VME electronics, cabling, …)
- infrastructure installation (new optical table & cover, cabling, rack preparation, MTCA systems, …)
- **MLO1** laser lock (RF)
- commissioning of **7 optical links**

Phase 2 (summer 2019)

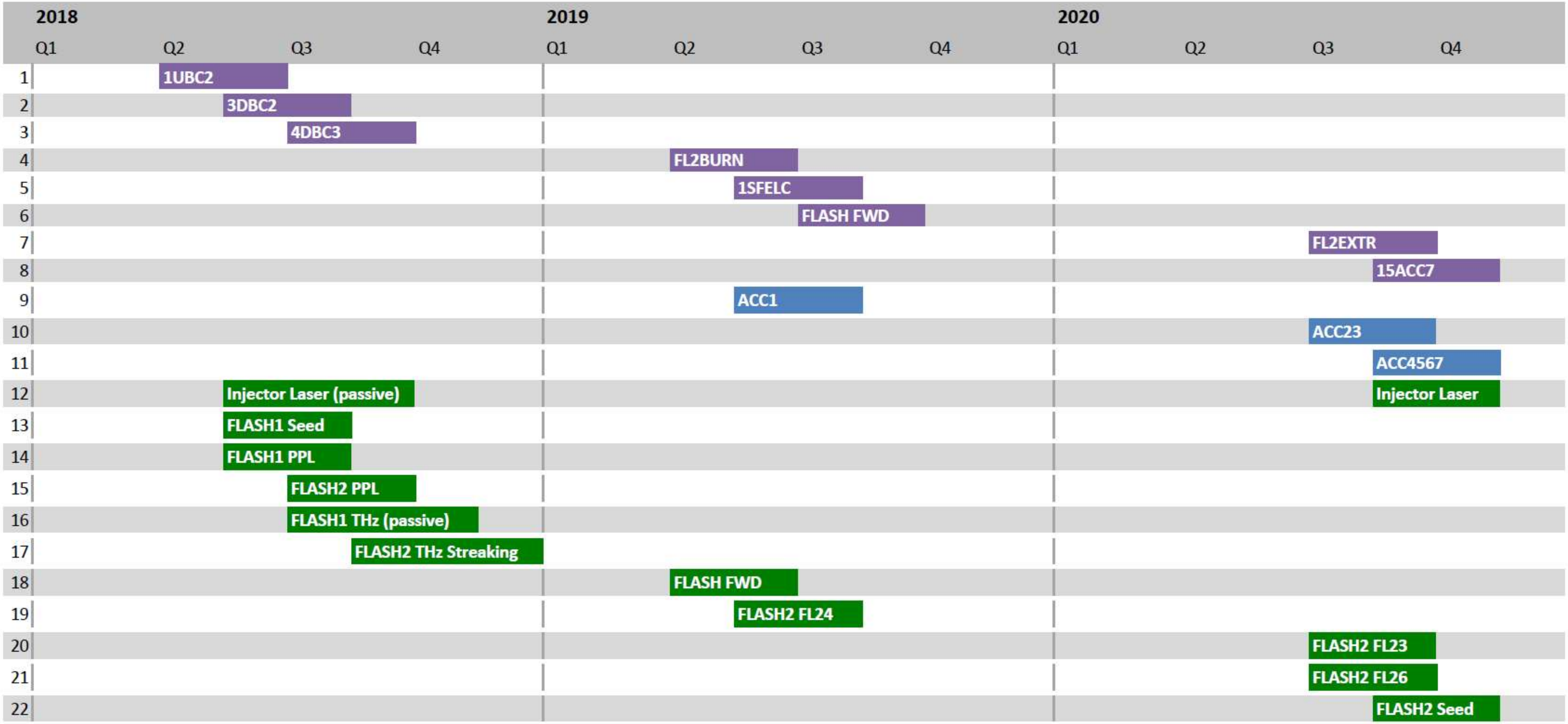
- commissioning of **6 optical links**
- **MLO2** laser lock (RF)

Phase 3 (summer 2020)

- main rack → MO room
- commissioning of **8 optical links**
- **MZM-based** MLO lock

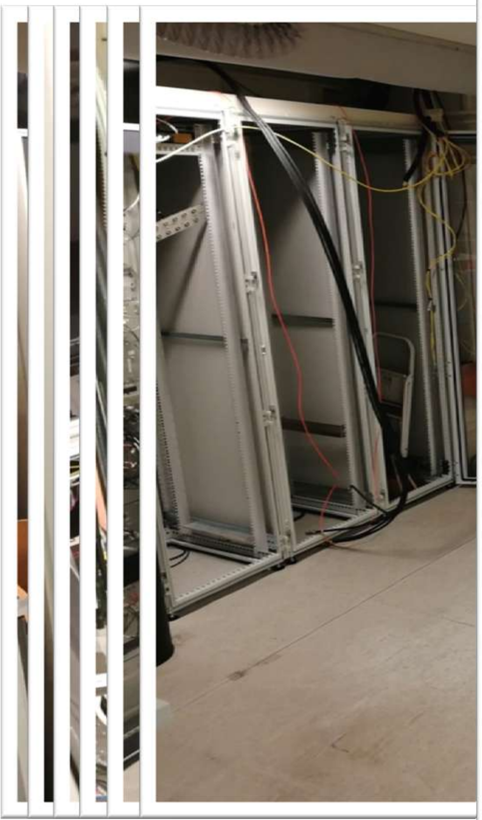
Optical Links at FLASH

Timeline: Link Commissioning



Summer Shutdown 2018

Work in progress…



before…

after 7 weeks of work…

FLASH LbSync Upgrades 2018+

Status & Next Steps

already installed/upgraded

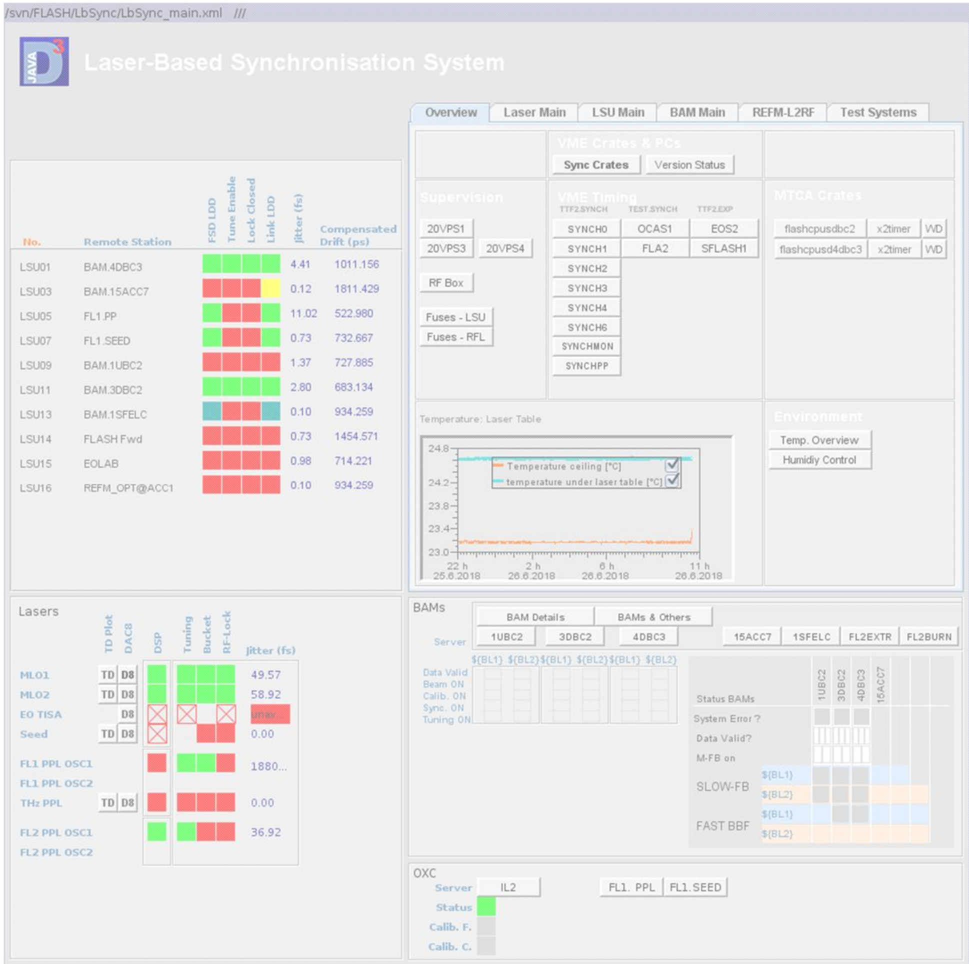
- main distribution system with **infrastructure for 12 LSUs**
- 7 fiber links in operation: **jitter 0.5 fs**
- laser synchronization
  - MLO1 RF-based: **jitter 17 fs**
  - pump-probe laser FLASH1/2: **jitter 5 fs**

next steps

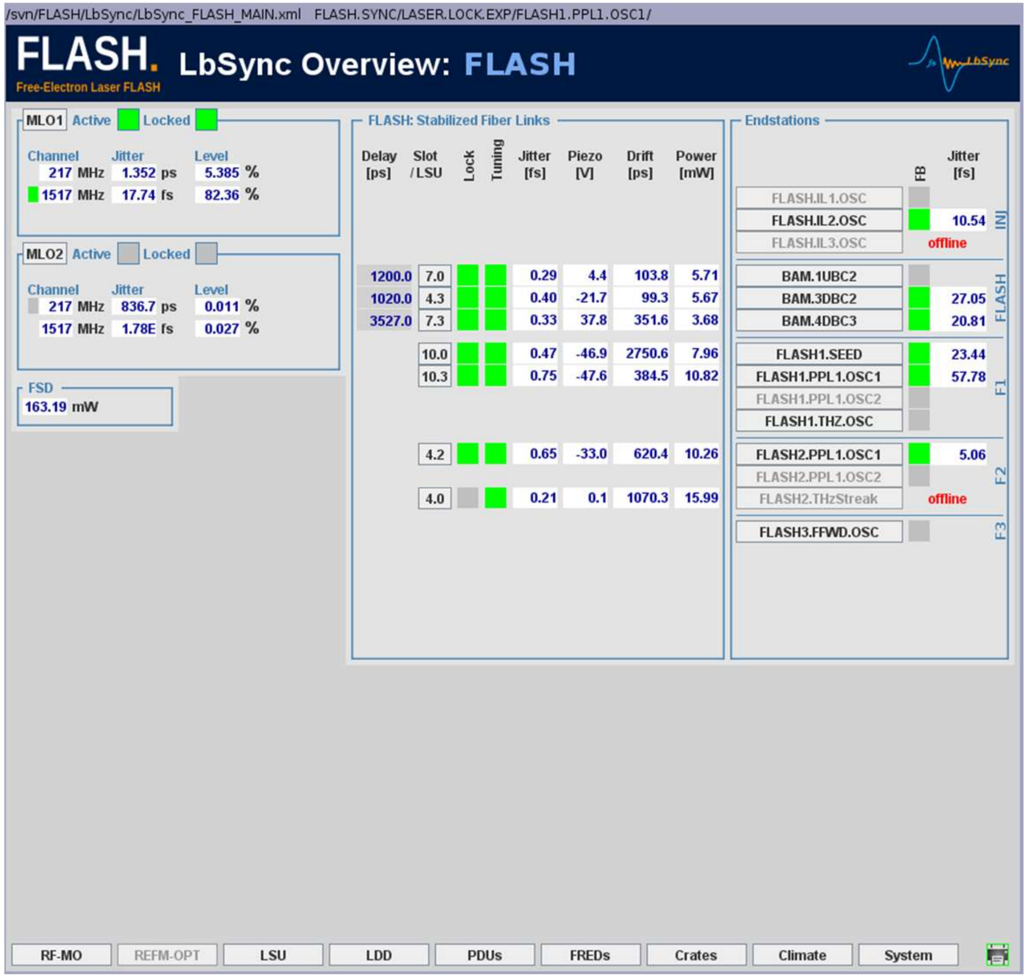
- fiber links
  - 6 additional links 2019
- laser synchronization
  - MLO2 installation – **ongoing**
  - injector laser 1 OXC – **ongoing**
  - FLASH2 THz streaking laser synchronization – **ongoing**
  - PPL: redundant systems for FLASH1 & FLASH2 – Q2/2019
  - exchange remaining VME systems by MTCA .4 (FLASH1 seed, THz beamline) – Q2/2019

DOOCS Controls

Before…



After.



Thanks.